LA-UR-13-25910
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Title: Laser Engineered Net Shaping Process Characterization

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Intended for: Report

Issued: 2013-08-02 (Rev.1)

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Laser Engineered Net Shaping Process Characterization

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Project Goal

The thermo-mechanical characterization of additive manufacturing, specifically the Laser Engineered Net Shaping *(LENS)* process has become a priority research area at Los Alamos National Laboratory. The first study on LENS conducted at LANL is being conducted as collaboration between LANL and the University of Texas at Austin as research for a master's thesis. This project takes a unique two path approach that merges both experimental and computational data in an attempt to gain further broad spectrum process knowledge of direct laser deposition as a means of additive manufacturing.

Theory

In order to properly integrate experimental results with modeling, a material system must be selected that will leave markers of process characteristics that can be seen through post deposition microscopy. In order to validate the model, peak temperatures and cooling rates must be able to be measured through post deposition microscopy. Pearlite spacing in plain low carbon steel provides the ability to post process these characteristics; therefore 1018 steel was selected as the material system. Additionally residual stress in the deposited samples will be experimentally measured to determine the ability of computational simulations to predict dynamic residual stress buildup in components.

In order to do a limited number of time efficient tests, a two degree of freedom system was set up that would effectively test thermo-mechanical response to changes in laser energy per unit length and powder feed rate.

Experimental

Powder Preparation

The powder used is a -100/+200 *(-149μm/+74μm)* mesh 1018 steel. The powder was sent to Exova Corporation for Inductively Coupled Plasma Mass Spectroscopy *(ICP-MS)* testing to determine metallic composition. Additionally Horiba interstitial analysis was done at LANL to determine the Carbon and Sulfur content. The results are shown below:

	Metallic Impurities														
	Al	Sb	As	Cr	Co	Cu	Ge	Mn	Mo	Ni	P	Sn	W	V	Zn
%w	0.002	0.0013	0.004	0.052	0.005	0.073	0.002	0.78	0.016	0.062	0.004	0.007	0.001	0.057	0.007
ppm	20	13	44	520	47	730	22	7800	160	620	40	66	14	570	71

Figure 1: EXOVA ICP-MS composition

	Non-metallic impurities	
	C	S
%wt	0.1939	0.0225
ppm	1939	225

Figure 2: LANL Horiba Interstitial Analysis

	Alloying Elements Weight%				
	Fe	C	Mn	P	S
ASM 1018	99.25-98.5	0.15-0.2	0.6-0.9	0.04 max	0.05 max
Powder Used	98.7099	0.1939	0.78	0.004	0.0225

Figure 3: Comparison to AISI 1018

From the combination of ICP-MS and Interstitial Analysis test done it is evident that the powder being used is indeed indicative of ASM 1018 steel as expected.

Baseplate Preparation

Eleven 5'' x 4'' x ¼ " cold rolled 1018 blanks were fabricated as baseplates for laser deposition. Each baseplate was cut to size from a larger bar and de-burred. The plates were then placed in an ultrasonic detergent bath to remove any grease or residue from machining. The plates were then individually measured, weighed, and engraved with a number to track them throughout the process.

Fabrication

Of the eleven baseplates prepared ten will be fabricated, each with three 3'' long deposition tests per blank. Each 1018 steel blank will have a single pass deposition, a two pass deposition, and a 1 inch tall wall. The combination of the three tests will yield model inputs, secondary pass effects, measurable experimental data, as well as testable components. Additionally, thermocouple and strain gauge placement on the baseplates will allow for in-situ temperature and strain data for the baseplate near the depositions.

Stress-Strain Analysis

In order to determine residual stress in the deposited wall we will use the inverse strain measurement of the slit cutting method. In this experiment the baseplates will be sectioned down to only a quarter inch on each side of the wall deposit using Electric Discharge Machining. After the walls are sectioned out the sample will be reoriented in the machine and incrementally cut in the center from the top of the deposited wall towards the baseplate. As small cuts are made the strain relaxation will be recorded by a strain gauge on the backside of the baseplate. This technique has shown to be effective for very complicated geometries and is ideal for a simple wall that will exhibit only plane stress. This test must be done prior to all other measurements and microscopy because in order to obtain the residual stress the samples must be destructively tested by sectioning them down the middle. This test will result in ten samples cut down the middle into equal ~1 ½ inch sections. One of the halves of each sample will be used strictly for microscopy and the second half will be a backup or possibly used for micro-tensile specimens, time permitting.

Microscopy

After EDM sectioning the samples will be taken back to the University of Texas for microscopy to determination peak temperatures, and cooling rates, dilution, and additive pass interaction at different specific power levels. Temperature evolution will be documented heavily and will be used as inputs to the SysWeld code.

Computational

As of 7/24/2013 we have begun to run single pass deposition on SysWeld with thermo-mechanical solvers. Once experimental results can be used to modify parameters and validate the single and double pass depositions, the larger wall will simply be the addition of more weld trajectories and an extended computation time.

The validated and verified computation results will be compared to experimental results to determine where numerical simulations reflect observed experimental data and where they deviate from the observed values. The local parameters of interest are dilution, peak temperatures, cooling rates, and residual stress, all of which will be measured experimentally and obtained computationally.

Timeline

August 15th, 2013: 10 Samples Fabricated at Optomec (1 as residual stress test specimen)

August 23rd, 2013: Slit cutting method residual stress measurement test completed and data obtained for refinement and inverse calculation

October 14th, 2013: Microscopy based experimental data on its way to being obtained and documented. At least 3 model parameters made ready for input into SysWeld.

October 18th, 2013: Weeklong trip to Los Alamos to begin V&V on SysWeld Simulations. Set up a suite of 3 simulations to run in series.

December 13th, 2013: Depart Austin for on-site work at Los Alamos (Subject to Finals Schedule)

January 10th, 2014: Depart Los Alamos to resume classes at University of Texas

February 1st, 2014: Begin compiling and writing Thesis

March 1st, 2014: Finish microscopy of all nine samples and have all relevant data documented

May 2nd, 2014: Thesis Completed, DC reviewed, LA-UR'd, and submitted to Graduate Dean

Conclusion

In summation this project will come to fruition in 9 months' time and will be a broad based computational and experimental process characterization of directed laser deposition, specifically the LENS process. The peak temperatures, cooling rates, residual stress, dilution, and other properties of interest will be examined as a function of laser power and laser speed and used to further the understanding of the process environment seen in additive manufacturing

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